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REVIEW OF SOILS DESIGN, CONSTRUCTION AND PERFORMANCE OBSERVATIO--ETC(U)
JAN 68 C C TRAHAN, F MITRONOVAS

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JAN. 1968

TECHNICAL REPORT NO. 3-642

REVIEW OF SOILS DESIGN, CONSTRUCTION AND PERFORMANCE OBSERVATIONS OVERBANK STRUCTURE OLD RIVER CONTROL

APPENDIX A: PUMPING TESTS AND WELL CLEANING OPERATIONS, 1966

by

C. C. Trahan

F. Mitronovas

January 1968

Sponsored by

The President, Mississippi River Commission

Conducted by

U. S. Army Engineer Waterways Experiment Station

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FOREWORD

This is an appendix to one of a series of reports on foundation and soil mechanics features of recently completed flood control and navigation structures in the U. S. Army Engineer Division, Lower Mississippi Valley, Corps of Engineers. These studies are being conducted for the Engineering Division of the Mississippi River Commission (MRC), Corps of Engineers, by the U. S. Army Engineer Waterways Experiment Station (WES).

The overbank structure for Old River Control was designed by MRC and built under the supervision of the U. S. Army Engineer District, New Orleans (NOD), La. Geological studies, foundation investigations, and soil design studies were made by WES. Engineering measurement devices were installed and observations were made by NOD. Details of the above-listed studies are given in the basic report. Relief well pumping tests were performed by WES under the direction of Mr. A. L. Mathews, Soils Division, WES. Water samples from relief wells were analyzed by the WES Concrete Division laboratory.

This appendix contains a description and analysis of the pumping tests performed by WES in 1966; it was prepared by Messrs. C. C. Trahan and F. Mitronovas under the direction of Messrs. W. J. Turnbull, A. A. Maxwell, J. R. Compton, and W. C. Sherman, Soils Division, WES. The MRC and NOD reviewed and approved the report prior to publication.

Director of WES during the preparation of this report was COL John R. Oswalt, Jr. Technical Director was Mr. J. B. Tiffany.

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CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	25.4	millimeters
feet	30.48	centimeters
miles	1.609344	kilometers
liquid pints (U. S.)	0.473179	cubic decimeters
gallons (U. S.)	3.78543	cubic decimeters
cubic feet per minute	0.028317	cubic meters per second

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SUMMARY

This appendix is the first in a series of reports presenting the results of tests performed at intervals of several years on the relief wells at the Overbank Structure, Old River Control, near Natchez, Miss. The tests reported herein were performed in 1966 by the U. S. Army Engineer Waterways Experiment Station (WES) and included well pumping tests, analysis of well water samples, and well sounding and cleaning operations. These tests were conducted to determine the extent to which the efficiency of the relief wells had decreased since their installation in 1957 and to clean by surging those wells with specific yields of 80 percent and less of their original specific yields.

Chemical analyses of well water samples indicate that the water is somewhat corrosive and contains a large amount of iron. In the presence of bacteria, incrustation or tuberculation of the well screens may occur under these conditions.

Prior to pumping tests, each well was sounded to determine the thickness of sediment in the well. Thicknesses varied from 0.0 to 8.9 ft; most of the sediment entered the wells after 1957. The measured thickness of sediment after pumping and cleaning varied from 0.0 to 2.1 ft.

Initial pumping tests on all wells indicated specific yields from 0 to 71 percent of the original specific yield, with an average of about 34 percent. After the wells were cleaned by surging, the specific yields increased to 6 and 87 percent of the original specific yields and averaged about 47 percent.

The rate of sand infiltration was determined by measuring the amount of sand entering the wells during pumping tests. The infiltration rates varied from none in some wells to 21 pints per hour in one well. Several wells may not be stable, as indicated by the high rate of sand infiltration.

The effectiveness of the relief well system in reducing uplift pressures was evaluated from factors of safety against uplift, computed by taking into account the increased head loss through well filters and screens observed in pumping tests. The computed factor of safety was about 1.9 before cleaning, and 2.2 after cleaning. In the original design, the computed factor of safety was 3.3.

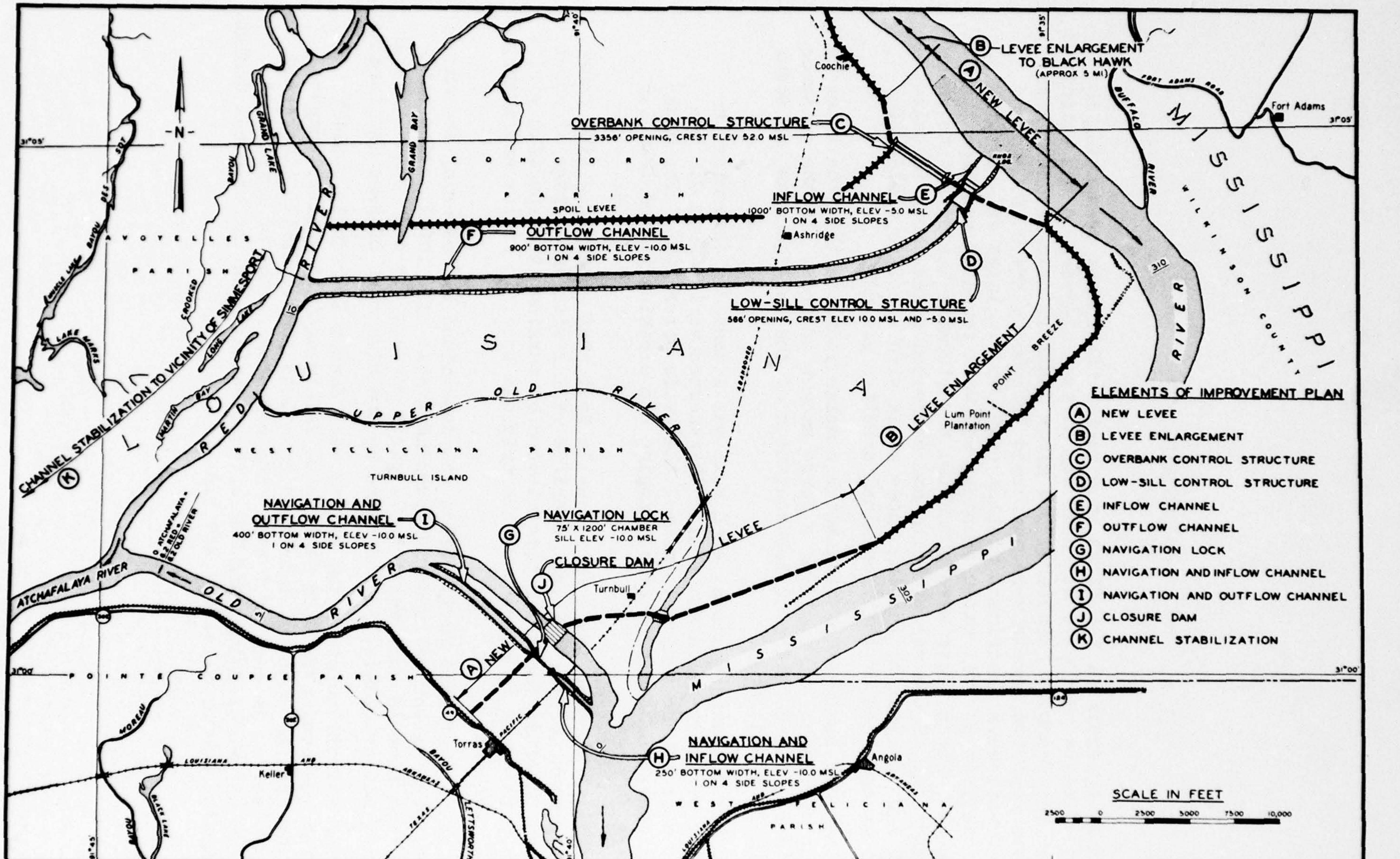

Fig. A1. Old River control plan

REVIEW OF SOILS DESIGN, CONSTRUCTION
AND PERFORMANCE OBSERVATIONS
OVERBANK STRUCTURE, OLD RIVER CONTROL

APPENDIX A: PUMPING TESTS AND WELL CLEANING OPERATIONS, 1966

PART I: INTRODUCTION

Description of Structure

1. The overbank structure, located on the west bank of the Mississippi River approximately 35 miles* south of Natchez, Miss. (see fig. A1), is a reinforced concrete spillway with hinged timber-gate panels for control of flood flows. It is a major element in the plan for Old River control. The structure has a gross length of 3356 ft and contains 73 gate bays, each having a 44-ft clear opening between 2-ft-thick bridge piers. A plan and downstream elevation of the structure are shown in fig. A2, and a typical section is shown in fig. A3. The basic report** contains a more detailed description of the structure.

Relief Wells

2. Pressure relief wells were installed behind the overbank structure during the period April to August 1957 to reduce hydrostatic pressures in the sands beneath the structure. The well system was designed so that a factor of safety of at least 1.5 against uplift would be realized beneath or immediately downstream of the stilling basin during periods of high water. In the design of the system, there was assumed to be (a) an effective source of seepage entry 1500 ft riverward of the

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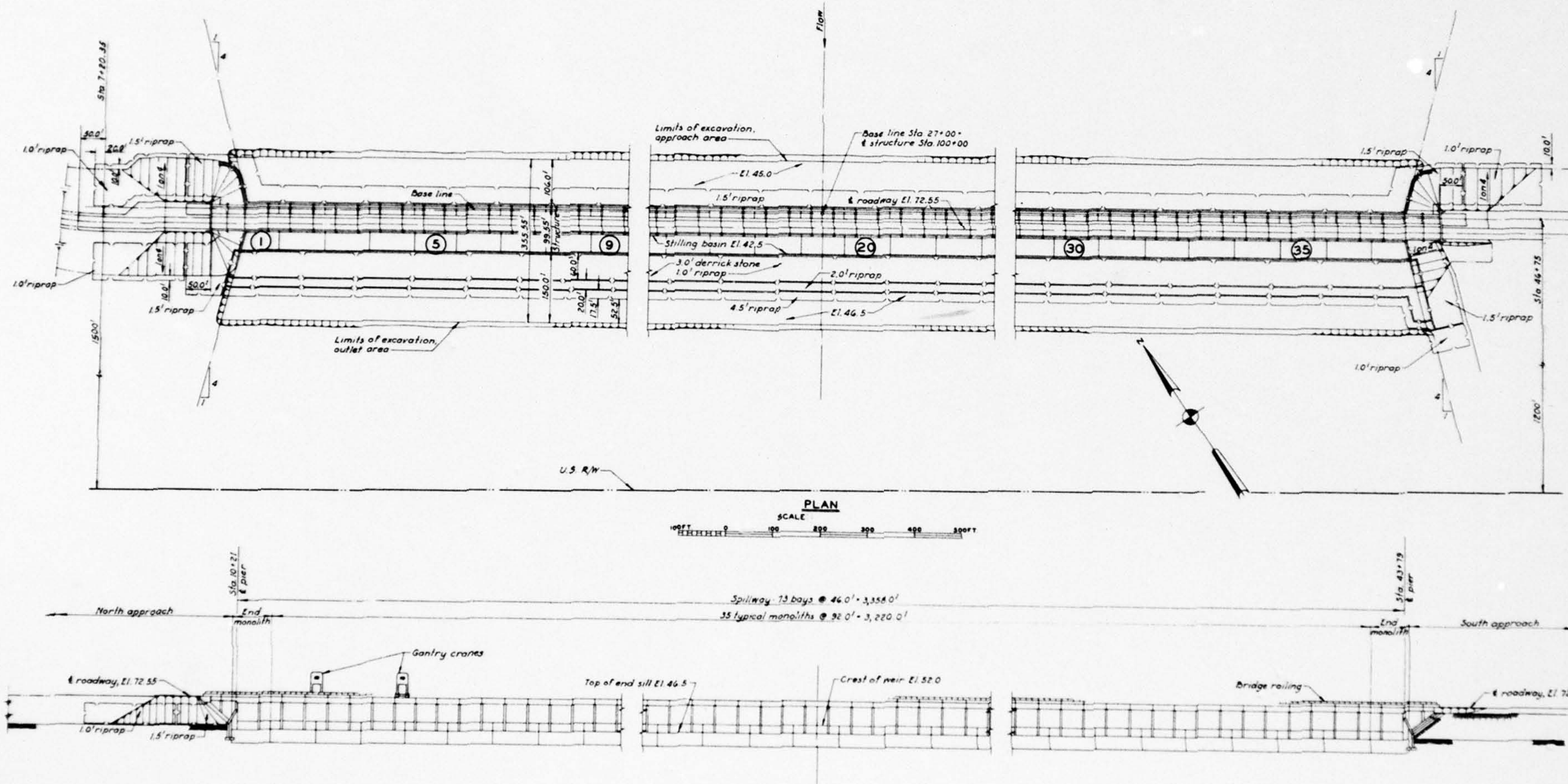
* A table of factors for converting British units of measurement to metric units is presented on page vii.

** W. C. Sherman, "Review of Soils Design, Construction, and Performance Observations, Overbank Structure, Old River Control," Technical Report No. 3-642, Feb 1964, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.



NOTE: ENCIRCLED NUMBERS ARE MONOLITH NUMBERS.

Fig. A2. Plan and elevation of structure

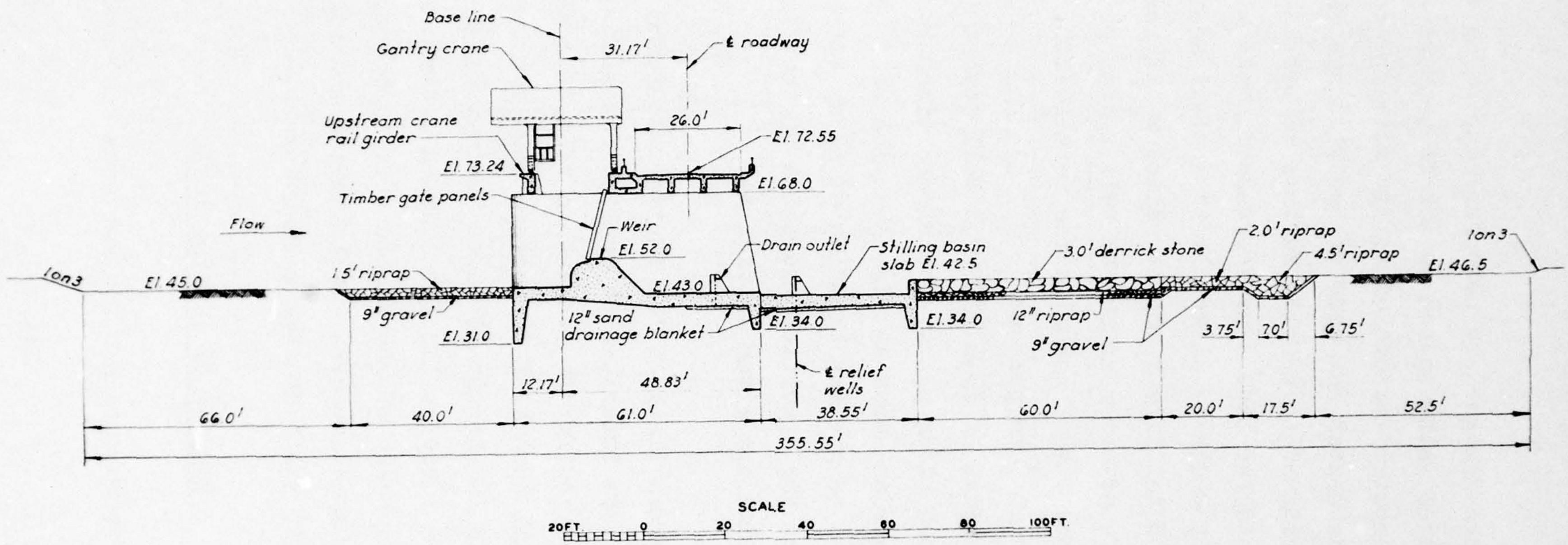


Fig. A3. Typical section

line of wells and (b) an infinite length of impervious topstratum landside of the structure.

Design

3. The wells were designed to penetrate approximately 50 percent of the aquifer. Nineteen wells spaced on 184-ft centers were required (see fig. A4). The computed factors of safety with respect to uplift were 4.8 and 3.3 at the center and ends of the well system, respectively. The well system was designed to provide factors of safety well in excess of 1.5, as it was considered that some decrease in well efficiency would occur with time, and it would be difficult to install additional wells at a later date. The total flow from the relief wells was estimated to be about 7.3 gpm per ft of net head on the well system or 150 gpm per well for a project flood stage, assuming the permeability of the foundation sands to be 500×10^{-4} cm per sec.

4. The wells consist of 8-in.-ID wood well screen (with 1/8-in. slots) and 8-in.-ID wood riser pipe. The risers discharge through the downstream baffle blocks as shown in fig. A5. The well outlets are provided with check valves to prevent backflow of muddy water into the wells. Details of the well and the specified gradation of the filter gravel around the screen section are given in fig. A5.

Installation

5. Since the permeability of the aquifer was found to increase with depth, the wells were installed to penetrate about 60 percent of the actual depth of the aquifer to achieve an effective penetration of 50 percent. The nominal length of the screen sections varied from 56 to 64 ft, except for wells 16 through 19 which had nominal lengths varying from 76 to 104 ft. The latter wells are located between sta 38 and sta 44 (see fig. A4), where the base of the aquifer (Tertiary deposits) is as much as 80 ft deeper than elsewhere. Installation and initial pumping test data for the relief wells are shown in table A1.

Purpose of Pumping Tests

6. The overbank structure has not yet been subjected to a significant

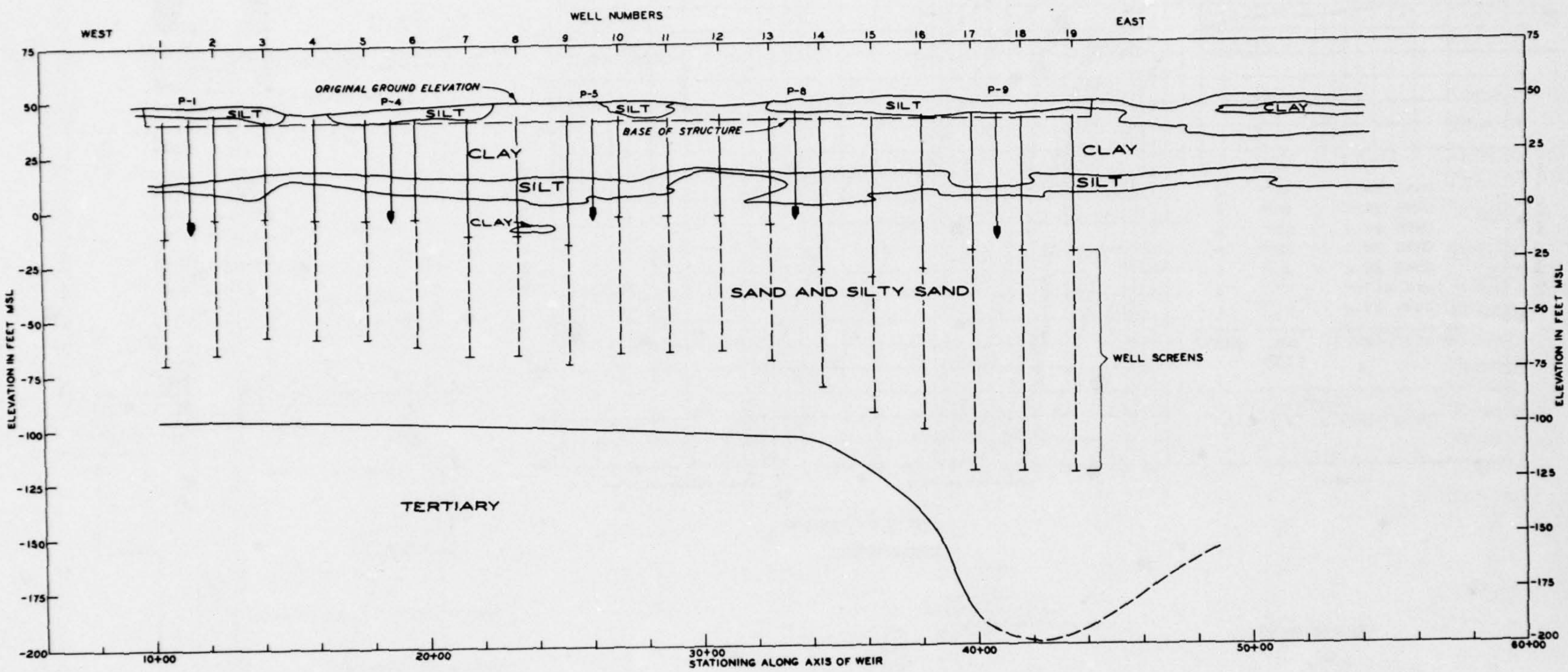


Fig. A4. Locations of relief wells showing depths of penetration

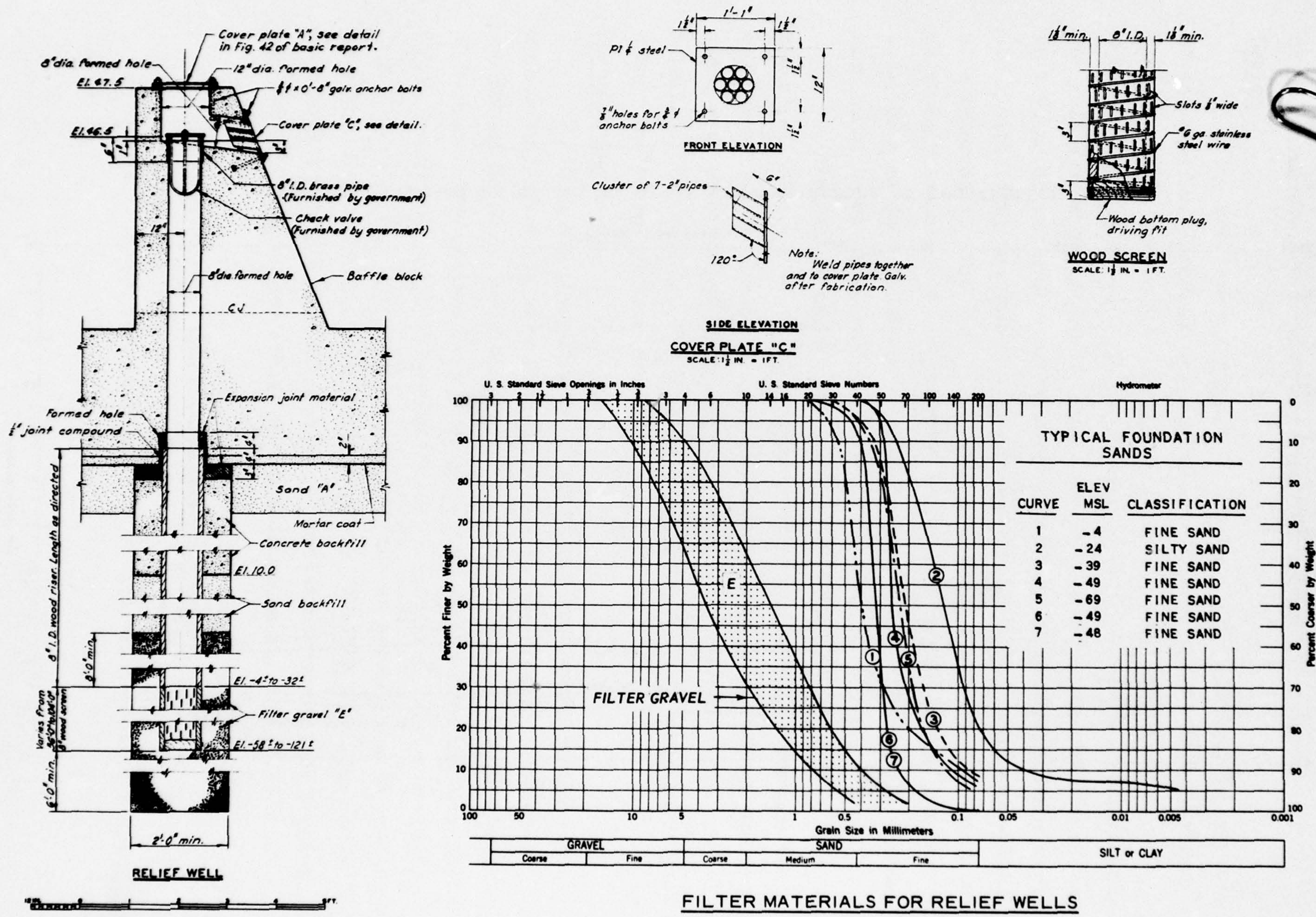


Fig. A5. Details of relief wells and gradation of filter gravel

Table A1

Installation and Pumping Test Data for Relief Wells, 1957

			As-Installed Elevation, ft msl			Pumping Test Data		
Well	Location Station	Date of Installation	Inside Bottom of Well	Top of Well Screen	Top of Filter	Date	Specific Yield gpm/ft	Rate of Sand Infiltration pt/hr
1	10+48	8/5	-69.84	-11.99	-1.62	10/19	37	None
2	12+32	7/29	-65.70	-4.05	+6.00	10/18	41	Trace
3	14+16	7/18	-58.33	-4.24	+6.67	10/15	24	Trace
4	16+00	7/16	-58.64	-4.05	+6.80	10/14	38	Trace
5	17+84	7/9	-58.62	-4.02	+6.22	10/13	38	Trace
6	19+68	6/26	-62.29	-4.04	+6.00	10/12	48	Trace
7	21+52	6/19	-66.83	-12.12	-1.80	10/10	20	Trace
8	23+36	6/14	-66.59	-11.93	-1.50	6/15	45	Trace
9	25+20	6/12	-70.65	-15.97	-6.00	10/9	27	Trace
10	27+04	6/10	-66.17	-3.79	+6.50	6/19	55	Trace
11	28+88	5/29	-65.46	-3.73	+6.50	6/18	47	Trace
12	30+72	5/27	-65.48	-3.76	+6.50	6/1	61	Trace
13	32+57	5/24	-69.73	-8.05	+3.00	5/25	48	Trace
14	34+40	5/19	-82.04	-28.01	-15.34	5/31	51	Trace
15	36+24	5/14	-93.90	-32.10	-19.70	5/15	76	0.04
16	38+08	4/23	-101.36	-28.01	-16.20	4/25	68	0.08
17	39+92	4/16	-120.67	-20.28	+10.37	4/17	85	Trace
18	41+76	4/19	-120.65	-20.25	-7.50	4/20	94	Trace
19	43+60	4/8	-121.33	-20.63	-9.00	4/15	92	Trace

Note: All wells located 57 ft landside of center line of structure.

head since its completion; consequently, the wells have not flowed, and their effectiveness under operating conditions has not been demonstrated. Recommendations were made in the basic report (WES TM 3-642) that pumping tests be conducted periodically on selected wells to determine if the wells had decreased in efficiency since their installation. In May 1965, pumping tests were conducted by the U. S. Army Engineer District, New Orleans (NOD) on wells 1, 4, 8, 10, 12, 15, and 18. Results of these tests are summarized in table A2. The test results indicated that the efficiency of the wells had decreased considerably since installation; the specific yields of the wells tested were from 5 to 59 percent of their original specific yields. Consequently, it was decided that all wells should be pump-tested and that all wells showing specific yields less than 80 percent of their original specific yield should be cleaned by surging. The pump testing and cleaning operations were conducted by WES in May and June 1966. This appendix presents the results of the pumping and cleaning operations performed in 1966.

Table A2

NOD Pumping Test Data, 1965

Well	Date of Test	River Stage ft	Discharge gpm	Drawdown in Well ft	Specific Yield gpm/ft	Average Specific Yield gpm/ft	Percent of 1957 Specific Yield
1	4 May	46.5	65	2.9	22		
			128	5.9	22	22	59
			186	8.8	21		
4	5 May	45.9	17	3.5	5		
			78	6.5	12	12*	32
			113	9.2	12		
8	6 May	45.3	47	4.4	11		
			87	6.8	13	13	29
			136	9.4	14		
10	7 May	44.7	50	3.0	17		
			115	5.8	20	19	35
			177	8.8	20		
12	10 May	43.1	48	2.9	17		
			103	5.5	19	19	31
			176	8.4	21		
15	11 May	42.7	13	4.8	3		
			30	7.0	4	4	5
			53	9.2	6		
18	12 May	42.2	63	2.1	30		
			155	3.9	40	39	41
			260	5.6	46		

* Excluding specific yield for 3.5-ft drawdown.

PART II: ANALYSIS OF WATER SAMPLES

Method of Sampling

7. In accordance with recommendations of the Mississippi River Commission (MRC), water samples were obtained from selected wells before well pumping tests were conducted. Wells 1, 7, 13, and 18 were selected for sampling; in these wells, water samples were taken at one-quarter, one-half, and three-quarter depths of the well and at the bottom of the well, and were designated as samples A, B, C, and D, respectively. Samples were taken with a sampler consisting of a 5-1/4-in.-OD plastic container, 12 in. long, having a capacity of about 1 gal, and a cork top. The sampler, with a weight attached, was lowered into the well to the desired depth, where the cork was pulled by means of a line attached to it. Then the sampler was raised, and each sample was identified and prepared for shipment to the U. S. Army Engineer Waterways Experiment Station (WES).

Results

8. The water samples were analyzed by the WES Concrete Division laboratory. The samples as received were quite turbid, and after they were allowed to stand, a brownish-black flocculent residue was noted. The water had a septic odor, and hydrogen sulfide (H_2S) was detected in most of the samples. The septic odor was more apparent in the samples from well 7 and in sample D from well 13 than in the remaining samples. All water samples contained a precipitated residue. Some analyses were made on the total solids and some were made on the dissolved solids.

9. The results of the chemical analyses are given in table A3. It should be noted that the total and dissolved solids for wells 7 and 13 were relatively uniform for the various well depths, whereas both the total and dissolved solids increased significantly for the two greatest depths at which samples were taken in wells 1 and 18. The volatile losses (loss on ignition) of the total solids represent losses due to organic matter, CO_2, or breakdown of carbonates or hydrates.

Table A3

Chemical Analysis of Water Samples from Wells 1, 7, 13, and 18

Constituent	Sample* A	B	C	D
Well 1				
Total Solids:				
Total solids, mg/l	484	464	877	1148
Volatile loss of total solids, mg/l	165	210	244	265
Calcium (Ca^{++}), mg/l	40	40	135	115
Sodium (Na^{+}), mg/l	62	51	50	55
Potassium (K^{+}), mg/l	6	6	6	6
Total iron ($Fe^{++,+++}$), mg/l	2	24	8	23
Alkalinity (to pH 3.5), epm	4.6	4.4	7.3	6.9
pH	7.4	7.1	7.2	7.2
Dissolved Solids:				
Dissolved solids, mg/l	370	352	584	537
Volatile loss of dissolved solids, mg/l	165	173	237	216
Sulfate ($SO_4^{=}$), mg/l	19	14	59	58
Chloride (Cl^{-}), mg/l	38	39	42	44
Calcium (Ca^{++}), mg/l	22	19	42	42
Sodium (Na^{+}), mg/l	32	31	41	30
Potassium (K^{+}), mg/l	5	5	6	6
Well 7				
Total Solids:				
Total solids, mg/l	541	464	556	599
Volatile loss of total solids, mg/l	279	221	256	260
Calcium (Ca^{++}), mg/l	34	26	31	33
Sodium (Na^{+}), mg/l	31	26	27	27
Potassium (K^{+}), mg/l	4	4	4	4
Total iron ($Fe^{++,+++}$), mg/l	12	11	22	29
Alkalinity (to pH 3.5), epm	2.9	2.5	2.5	2.3
pH	6.9	7.1	6.9	6.8
Dissolved Solids:				
Dissolved solids, mg/l	233	260	203	211
Volatile loss of dissolved solids, mg/l	105	132	130	121
Sulfate ($SO_4^{=}$), mg/l	19	24	24	22
Chloride (Cl^{-}), mg/l	11	14	12	14
Calcium (Ca^{++}), mg/l	19	19	17	18
Sodium (Na^{+}), mg/l	9	9	6	9
Potassium (K^{+}), mg/l	4	4	4	4

(Continued)

* In each well, samples A, B, and C were taken at one-fourth, one-half, and three-fourths of the depth of the well, respectively; and sample D was taken at the bottom of the well.

Table A3 (Concluded)

Constituent	Sample A	Sample B	Sample C	Sample D
Well 13				
Total Solids:				
Total solids, mg/l	677	566	587	555
Volatile loss of total solids, mg/l	303	235	237	266
Calcium (Ca^{++}), mg/l	41	42	39	44
Sodium (Na^{+}), mg/l	34	30	35	36
Potassium (K^{+}), mg/l	6	6	5	5
Total iron ($Fe^{++,+++}$), mg/l	17	13	14	13
Alkalinity (to pH 3.5), epm	4.4	4.4	4.4	5.0
pH	7.7	8.1	7.6	6.7
Dissolved Solids:				
Dissolved solids, mg/l	366	342	335	344
Volatile loss of dissolved solids, mg/l	151	132	132	160
Sulfate ($SO_4^{=}$), mg/l	51	49	45	15
Chloride (Cl^{-}), mg/l	21	29	27	25
Calcium (Ca^{++}), mg/l	31	34	33	33
Sodium (Na^{+}), mg/l	23	25	23	23
Potassium (K^{+}), mg/l	6	6	5	5
Well 18				
Total Solids:				
Total solids, mg/l	293	314	928	990
Volatile loss of total solids, mg/l	155	163	380	409
Calcium (Ca^{++}), mg/l	41	37	150	333
Sodium (Na^{+}), mg/l	19	20	36	38
Potassium (K^{+}), mg/l	4	4	5	5
Total iron ($Fe^{++,+++}$), mg/l	3	6	15	16
Alkalinity (to pH 3.5), epm	3.8	3.7	12.5	12.5
pH	7.0	7.5	7.7	7.6
Dissolved Solids:				
Dissolved solids, mg/l	249	250	858	842
Volatile loss of dissolved solids, mg/l	134	148	337	342
Sulfate ($SO_4^{=}$), mg/l	3	4	88	96
Chloride (Cl^{-}), mg/l	17	12	34	43
Calcium (Ca^{++}), mg/l	20	19	33	36
Sodium (Na^{+}), mg/l	16	15	25	27
Potassium (K^{+}), mg/l	4	4	5	5

10. The most prevalent cations found in the water were calcium and sodium. Most of the samples contained unusually large amounts of iron with the exception of the samples taken at the shallowest depths in wells 1 and 18.

11. The pH values of the well samples ranged from slightly acidic to slightly basic. The greatest fluctuation with depth was noted in well 13. For this well, the pH of sample D (6.7) was considerably less than the pH of sample A (7.7). Sample D with the low pH contained more H_2S than the other three samples from well 13, and the sulfate values reflect this fact. Low pH values were also obtained for well 7.

12. The presence of organic matter was confirmed by microscopic examination of the samples. The organic matter contributes to the polluted odor of the water and may be a source of nuisance bacteria. Some bacteria produce H_2S, and some either liberate iron by utilizing organic radicals to which the iron is attached or else they alter environmental conditions to permit solution or deposition of iron. Either of these conditions appears to be likely in these well waters.

13. In conclusion, the test results indicate that incrustations or tuberculations may form due to iron. The water is somewhat corrosive, though not excessively so; however, this should have little bearing on the decrease in efficiency of the wells with time.

PART III: INSPECTION AND SOUNDING OF WELLS

Inspection of Well Outlets and Check Valves

14. Before the pumping and cleaning operations were performed on a well, the well outlets and check valves were inspected to determine whether they were in satisfactory condition to prevent backflooding of the wells. The well outlets were found to be in good condition; no obstructions were found in any of the outlets, and none of them were damaged in any way. The check valves were in satisfactory condition. Deterioration of the rubber gaskets for the valves was observed on several of the well tops. Although none of the gaskets were deteriorated enough to prevent the valves from performing satisfactorily, the gaskets may not last much longer and therefore should be replaced.

Sounding of Wells

15. Prior to testing, each well was sounded to determine the amount of sediment in the well. The sounding was made by measuring from the top of the baffle block (see fig. A5) to the top of the sediment in the well with a steel tape attached to a sounding weight consisting of a 3/4-in.-diam, 1-ft-long pipe with a standard flange on the bottom. The well was also sounded before and after surging to determine the amount of material carried into the well. A final sounding was made after surging and pumping of the well was completed. Well 16 could not be sounded as an obstruction was found in the well at a depth of about 21 ft.

16. Well sounding data are shown in table A4. The amount of sediment in a well was determined by subtracting the depth to the sediment from the inside depth of the well. The inside depth of the well was estimated by subtracting the elevation of the bottom of the well as-installed from the assumed elevation of the top of the baffle block (el 47.5*). As shown in table A4, the thickness of sediment in the wells in 1966 before

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* Elevations are in feet referred to mean sea level.

Table A4

Well Sounding Data

Well	Sediment in Well in 1957 ft	Est Depth of Well* ft	1966 Before Pumping Depth to Sediment ft	1966 Before Pumping Sediment in Well ft	1966 After Pumping Depth to Sediment ft	1966 After Pumping Sediment in Well ft
1	0.30	117.3	116.48	0.8	116.50	0.8
2	0.22	113.2	112.18	1.0	112.60	0.6
3	0.04	105.8	102.37	3.4	106.10	-0.3
4	0.27	106.1	104.83	1.3	106.12	0
5	0.21	106.1	106.10	0	106.31	-0.2
6	0.34	109.8	105.54	4.3	107.90	1.9
7	0.28	114.3	114.44	-0.1	114.18	0.1
8	0.31	114.1	105.21	8.9	113.95	0.1
9	0.25	118.1	113.45	4.6	116.96	1.1
10	0.02	113.7	109.25	4.5	--	--
11	0.06	113.0	111.89	1.1	112.96	0
12	0.20	113.0	110.56	2.4	112.75	0.2
13	0.20	117.2	113.44	3.8	116.54	0.7
14	0.27	129.5	126.10	3.4	129.15	0.3
15	0.18	141.4	136.80	4.6	139.30	2.1
16**	0.15	148.9	--	--	--	--
17	0.42	168.2	159.31	8.9	167.18	1.0
18	0.46	168.2	165.91	2.3	167.05	1.2
19	0.18	168.8	167.47	1.3	--	--

* Depth of well was estimated by subtracting initial elevation of bottom of well from assumed elevation of top of baffle block (el 47.5).

** An obstruction was found in this well at a depth of about 21 ft, and soundings could not be made.

pumping varied from none in well 5 to 8.9 ft in wells 8 and 17. Most of the sediment entered the wells after 1957, as indicated by comparing the 1957 and 1966 values. In wells 3, 5, and 7, the maximum depths obtained by soundings either before, during, or after the 1966 pumping and surging operations were slightly more (by 0.1 to 0.3 ft) than the estimated inside depth of the wells; this indicates that either the assumed elevations of the tops of the wells are incorrect or that the well screens and risers have elongated due to settlement of the filter around the wells.

PART IV: 1966 WELL PUMPING TESTS AND CLEANING OPERATIONS

River Stages

17. Pumping and cleaning operations were begun on 4 May 1966 and completed on 17 June 1966. During this period, the Mississippi River rose from el 40.2 ft on 4 May to a maximum elevation of 45.0 ft on 18 May. The river then dropped to el 24.5 ft on 17 June.

Equipment

18. As there was approximately 4 to 4-1/2 ft of water in the stilling basin during pumping and cleaning operations, equipment for the field operations had to be mounted on a floating barge. The equipment consisted of the following:

- a. A gasoline-powered, centrifugal jet pump with a rated capacity of 525 gpm at a 100-ft head, used for pump testing the wells.
- b. A Hersey-Sparling recording meter, used to measure flow from the wells. This meter was connected to the pump-discharge line.
- c. A surging block consisting of two 7-1/2-in.-diam rubber disks mounted on a 4-in. steel shaft, used to clean the wells.
- d. A 5-in.-diam by 6-ft-long piston-type bailer, used to remove material from the wells. The bailer was subsequently cut to a length of 4 ft so it would fit wells with bent risers.

Pumping Tests and Cleaning Operations

19. The wells were pump-tested and cleaned consecutively, starting with well 19 on the east end of the structure and ending with well 1 on the west end of the structure. Well 16 was omitted because of the obstruction found at a depth of about 21 ft. Each well was first pump-tested to determine its specific yield; generally, this initial test was conducted at three different drawdowns. The initial pumping tests on

all wells indicated specific yields from 0 to 71 percent of the original specific yield. Therefore, all wells were cleaned at least once. The initial cleaning operation consisted of six surging cycles, each cycle consisting of 15 round trips with the surging block. The well was pumped at a rate of about 50 gpm while it was being surged. Material in the wells was removed with a bailer before pump-testing and after each surging cycle. A second pumping test was conducted on the well after it was cleaned. If the second test showed that the surging had significantly increased the specific yield, the well was surged again with three surging cycles. All operations were completed on a well before moving to the next well.

20. During pumping and cleaning operations, it was noted that the risers of many of the wells were out of line. This was first observed in well 18 when the 6-ft-long bailer would not fit in the well. The bailer had to be cut to a 4-ft length and one of the rubber disks removed from the surging block to permit their use in the well. The bend in the riser usually occurred just a few feet below the top of the well. The crooked risers may be the result of improper installation or of cyclic vertical movements of the stilling basin after construction (see basic report).

Test Results

21. A summary of the 1966 pumping test data is shown in table A5. Plots of observed discharge versus drawdown are shown in plates A1 through A5. Also shown in these plots are similar data for the 1957 pumping tests. Fig. A6 is a comparison of the computed specific yield from the 1966 pumping tests and the original specific yields of the wells. Before the wells were cleaned, the specific yields of the wells varied from 0 to 71 of their original specific yields and averaged about 34 percent. After the wells were cleaned, the specific yield varied from 6 to 87 percent of their original specific yields and averaged about 47 percent. In all cases, cleaning the wells increased their specific yield. For some wells, such as wells 2, 4, 13, and 18, cleaning resulted in a significant increase in their specific yields, whereas for other wells, such as wells 7, 9, 12, and 19, the

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Table A5

1966 Pumping Tests and Surging Data

Well	Date	River Stage ft msl	Pumping Data: Discharge gpm	Drawdown in Well ft	Specific Yield gpm/ft	Rate of Sand Infiltration pt/hr	Surging Data: No. of Surging Cycles*	Material Entering Well ft**	Discharge While Surging gpm
1	16 June	25.0	54	2.1	26	--	--	--	--
	16 June	25.0	104	3.9	27	--	--	--	--
	16 June	25.0	146	6.0	24	1.4	--	--	--
	16 June	25.0	--	--	--	--	6	0.84	40
	17 June	24.5	52	1.9	27	--	--	--	--
	17 June	24.5	124	4.2	30	--	--	--	--
	17 June	24.5	178	6.1	29	3.4	--	--	--
2	15 June	25.4	26	2.0	13	--	--	--	--
	15 June	25.4	62	4.2	15	--	--	--	--
	15 June	25.4	100	6.0	17	2.3	--	--	--
	16 June	25.0	--	--	--	--	6	1.87	50
	16 June	25.0	53	1.9	28	--	--	--	--
	16 June	25.0	122	4.2	29	--	--	--	--
	16 June	25.0	178	6.1	29	21.4	--	--	--
	16 June	25.0	--	--	--	--	3	0.70	50
	16 June	25.0	60	2.0	30	--	--	--	--
	16 June	25.0	126	4.1	31	--	--	--	--
	16 June	25.0	178	6.1	29	10.0	--	--	--
3	15 June	25.4	0^+	--	--	--	--	--	--
	15 June	25.4	--	--	--	--	6	0.48	30
	15 June	25.4	25	4.2	6	--	--	--	--
	15 June	25.4	33	6.0	6	3.8	--	--	--
	15 June	25.4	--	--	--	--	3	0.23	30
	15 June	25.4	25	3.7	7	--	--	--	--
	15 June	25.4	35	5.3	7	2.7	--	--	--
4	13 June	26.9	60	3.9	15	--	--	--	--
	13 June	26.9	164	8.1	20	0.0	--	--	--
	13 June	26.9	--	--	--	--	6	0.55	50
	13 June	26.9	106	3.9	27	--	--	--	--
	13 June	26.9	193	8.4	23	--	--	--	--
	13 June	26.9	210	9.2	23	1.2	--	--	--
	14 June	26.0	74	3.1	24	--	--	--	--
	14 June	26.0	145	6.1	24	--	--	--	--
	14 June	26.0	210	9.0	23	1.2	--	--	--
	14 June	26.0	--	--	--	--	6	0.55	50
	14 June	26.0	72	2.9	25	--	--	--	--
	14 June	26.0	151	6.2	25	--	--	--	--
	14 June	26.0	--	--	--	--	3	0.42	50
	14 June	26.0	84	3.1	28	--	--	--	--
	14 June	26.0	152	6.0	25	--	--	--	--
	14 June	26.0	198	8.2	24	0.4	--	--	--
5	10 June	30.4	225	8.3	27	--	--	--	--
	10 June	30.4	315	11.5	27	0.0	--	--	--
	10 June	30.4	--	--	--	--	6	0.76	50
	10 June	30.4	150	4.2	35	--	--	--	--
	10 June	30.4	260	7.8	33	--	--	--	--
	10 June	30.4	315	9.7	33	1.8	--	--	--
6	9 June	--	0^+	--	--	--	--	--	--
	9 June	--	--	--	--	--	6	0.49	25
	9 June	--	10	4.5	2	--	--	--	--
	9 June	--	15	8.0	2	--	--	--	--
	9 June	--	28	11.5	2	0.8	--	--	--
	9 June	--	--	--	--	--	3	0.60	25
	9 June	--	13	4.4	3	--	--	--	--
	9 June	--	25	7.2	3	--	--	--	--
	9 June	--	35	11.9	3	0.0	--	--	--
7	8 June	33.4	11	15.6	1	0.0	--	--	--
	8 June	33.4	--	--	--	--	6	0.39	32
	8 June	33.4	31	4.2	7	--	--	--	--
	8 June	33.4	57	7.0	8	--	--	--	--
	8 June	33.4	102	12.5	9	1.5	--	--	--
	8 June	33.4	--	--	--	--	3	0.12	60
	8 June	33.4	48	4.0	12	--	--	--	--
	8 June	33.4	93	8.0	12	--	--	--	--
	8 June	33.4	126	12.2	10	0.5	--	--	--
8	7 June	35.0	80	11.9	7	0.0	--	--	--
	7 June	35.0	--	--	--	--	6	1.30	50
	7 June	35.0	48	4.0	12	--	--	--	--
	7 June	35.0	94	7.9	12	--	--	--	--
	7 June	35.0	139	11.9	12	1.0	--	--	--
	7 June	35.0	--	--	--	--	3	0.20	50
	7 June	35.0	56	4.0	14	--	--	--	--
	7 June	35.0	120	8.1	15	--	--	--	--
	7 June	35.0	180	12.0	15	0.0	--	--	--
9	6 June	36.4	40	3.9	10	--	--	--	--
	6 June	36.4	90	8.0	11	--	--	--	--
	6 June	36.4	134	12.0	11	0.0	--	--	--
	6 June	36.4	--	--	--	--	6	0.08	50
	6 June	36.4	56	4.0	14	--	--	--	--
	6 June	36.4	120	8.0	15	--	--	--	--
	6 June	36.4	181	12.0	15	0.0	--	--	--

(Continued)

* One surging cycle consisted of 15 strokes with a surging block.
** *Based on soundings before and after surging.*
\+ Discharge from well was too small to be measured.

Table A5 (Concluded)

Well	Date	River Stage ft msl	Pumping Data: Discharge gpm	Pumping Data: Drawdown in Well ft	Pumping Data: Specific Yield gpm/ft	Pumping Data: Rate of Sand Infiltration pt/hr	Surging Data: No. of Surging Cycles	Surging Data: Material Entering Well ft	Surging Data: Discharge While Surging gpm
10	26 May	43.3	71	3.3	22	--	--	--	--
	26 May	43.3	95	4.5	21	0.0	--	--	--
	3 June	40.1	--	--	--	--	6	0.22	60
	3 June	40.1	119	4.1	29	--	--	--	--
	3 June	40.1	240	8.3	29	--	--	--	--
	3 June	40.1	355	12.1	29	2.96	--	--	--
	3 June	40.1	--	--	--	--	3	0.27	60
	3 June	40.1	140	4.3	33	--	--	--	--
	3 June	40.1	251	8.3	31	--	--	--	--
	3 June	40.1	350	12.2	29	--	--	--	--
11	25 May	43.4	3	6.2	0.5	0.0	--	--	--
	25 May	43.4	--	--	--	--	6	0.85	45
	25 May	43.4	18	2.7	7	--	--	--	--
	25 May	43.4	38	6.1	6	--	--	--	--
	25 May	43.4	54	8.7	6	0.0	--	--	--
	25 May	43.4	--	--	--	--	3	0.51	45
	25 May	43.4	72	8.7	8	0.0	--	--	--
12	24 May	43.7	77	3.5	22	--	--	--	--
	24 May	43.7	133	6.1	22	--	--	--	--
	24 May	43.7	201	9.2	22	2.5	--	--	--
	24 May	43.7	--	--	--	--	6	0.65	50
	24 May	43.7	69	3.0	23	--	--	--	--
	24 May	43.7	151	6.2	24	--	--	--	--
	24 May	43.7	227	9.3	24	0.0	--	--	--
13	20 May	44.8	76	4.1	18	--	--	--	--
	20 May	44.8	144	8.3	17	--	--	--	--
	20 May	44.8	172	10.1	17	0.0	--	--	--
	20 May	44.8	--	--	--	--	6	0.0	50
	20 May	44.8	100	4.0	25	--	--	--	--
	20 May	44.8	182	7.0	26	0.0	--	--	--
	20 May	44.8	--	--	--	--	3	0.17	50
	23 May	44.1	98	4.0	25	--	--	--	--
	23 May	44.1	214	8.0	27	--	--	--	--
	23 May	44.1	240	9.0	27	--	--	--	--
14	18 May	45.0	38	3.2	12	--	--	--	--
	18 May	45.0	101	7.5	13	--	--	--	--
	18 May	45.0	162	11.2	14	0.0	--	--	--
	19 May	44.9	--	--	--	--	6	0.56	60
	19 May	44.9	80	3.9	20	--	--	--	--
	19 May	44.9	155	8.0	19	--	--	--	--
	19 May	44.9	240	11.9	20	0.0	--	--	--
15	16 May	44.8	66	4.0	17	--	--	--	--
	16 May	44.8	114	8.0	14	--	--	--	--
	16 May	44.8	155	12.0	13	0.0	--	--	--
	16 May	44.8	--	--	--	--	6	0.94	50
	16 May	44.8	78	4.2	19	--	--	--	--
	16 May	44.8	142	7.7	18	--	--	--	--
	16 May	44.8	216	12.2	18	0.0	--	--	--
17	12 May	44.0	117	4.0	29	--	--	--	--
	12 May	44.0	223	8.1	28	--	--	--	--
	12 May	44.0	318	12.1	26	--	--	--	--
	12 May	44.0	--	--	--	--	6	0.60	50
	12 May	44.0	153	4.1	37	--	--	--	--
	13 May	43.9	270	8.1	33	--	--	--	--
	13 May	43.9	390	12.1	32	--	--	--	--
18	10 May	42.8	216	4.2	51	--	--	--	--
	10 May	42.8	378	8.1	46	--	--	--	--
	10 May	42.8	448	10.0	45	1.3	--	--	--
	10 May	42.8	--	--	--	--	6	1.16	50
	11 May	43.2	212	3.2	66	0.7	--	--	--
	11 May	43.2	--	--	--	--	3	0.06	50
	11 May	43.2	205	3.0	68	--	--	--	--
	11 May	43.2	332	5.2	64	--	--	--	--
	11 May	43.2	433	7.2	60	1.5	--	--	--
19	4 May	40.2	103	3.8	27	--	--	--	--
	4 May	40.2	186	6.8	27	--	--	--	--
	4 May	40.2	253	9.8	26	0.0	--	--	--
	5 May	40.8	--	--	--	--	5	0.63	50
	5 May	40.8	180	6.0	30	0.0	--	--	--
	6 May	41.4	--	--	--	--	2	0.31	50
	6 May	41.4	176	6.1	29	0.0	--	--	--
	6 May	41.4	--	--	--	--	5	0.63	50
	6 May	41.4	286	9.2	31	0.0	--	--	--
	9 May	42.8	89	3.1	29	--	--	--	--
	9 May	42.8	157	6.1	26	--	--	--	--
	9 May	42.8	280	9.1	31	--	--	--	--

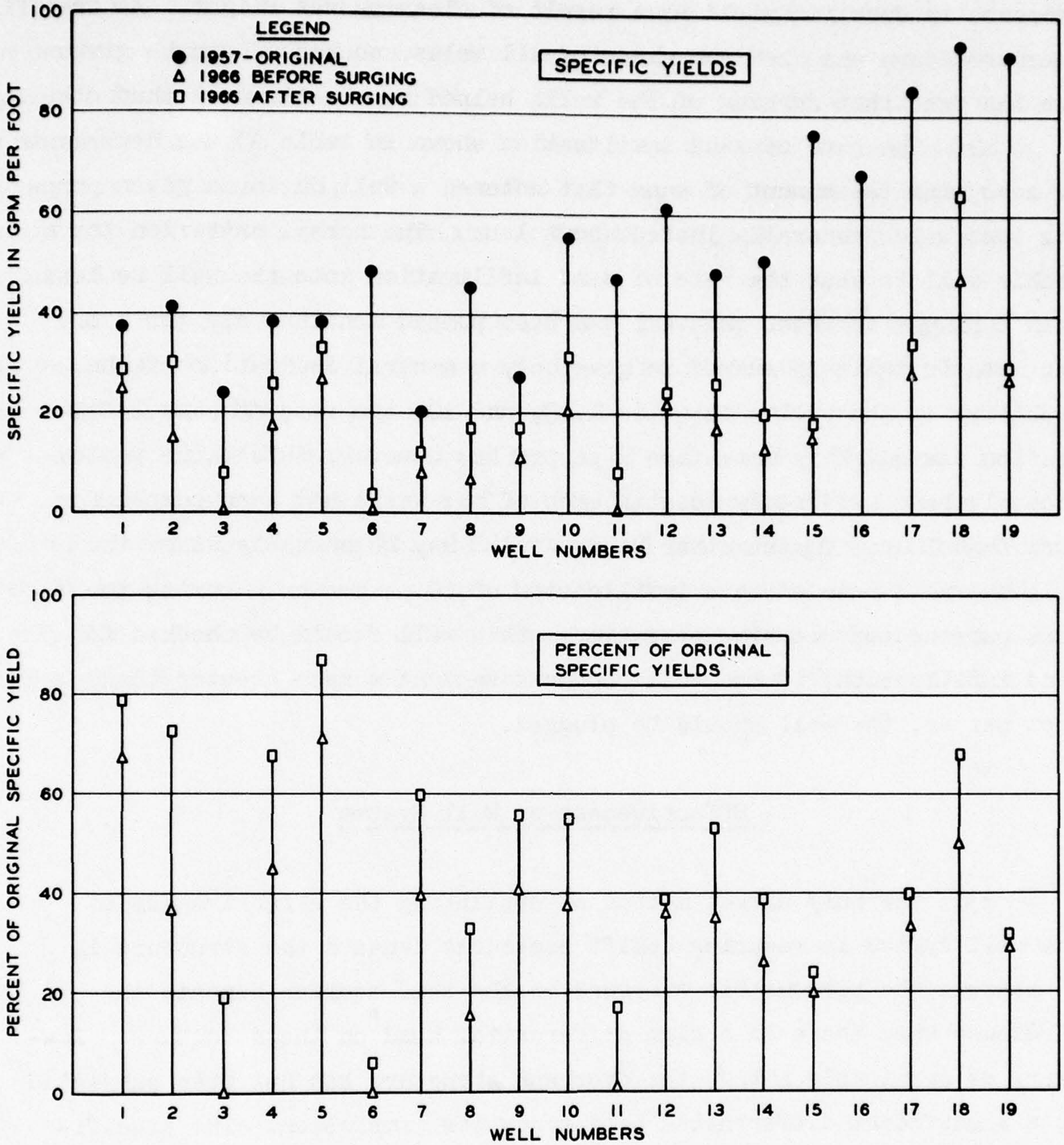


Fig. A6. Comparison of 1957 and 1966 specific yields

increase in specific yield as a result of cleaning was slight. As the same procedure was used for cleaning all wells, no reason can be given for the fact that surging of the wells helped some wells more than others.

22. The rate of sand infiltration shown in table A5 was determined by measuring the amount of sand that entered a well during a given pumping test which generally lasted about 1 hr. The normal criterion for a stable well is that the rate of sand infiltration into the well be less than 2 pt per hr after the well has been pumped continuously for 8 hr. The data in table A5 therefore give only a general indication of the stability of the well. In wells 1, 3, and 10, the rate of sand infiltration was slightly more than 2 pt per hr; however, this value would probably be considerably less if each of the wells had been pumped for more than 1 hr. On the other hand, well 2 may be unstable since the well showed a rate of sand infiltration of 10 pt per hr. During the next pumping and cleaning operations, this well should be checked for sand infiltration; if the well produces sand at a rate greater than 2 pt per hr, the well should be plugged.

Effectiveness of Well System

23. The only direct method of evaluating the effectiveness of the well system in reducing uplift pressures beneath the structure is to measure the piezometric pressure in the sand aquifer beneath the structure when there is a high differential head on the structure. However, as previously noted, the overbank structure has not been subjected to a significant differential head since its completion. The significance of the reduction in specific yields of the wells was determined indirectly on the basis of the following assumptions:

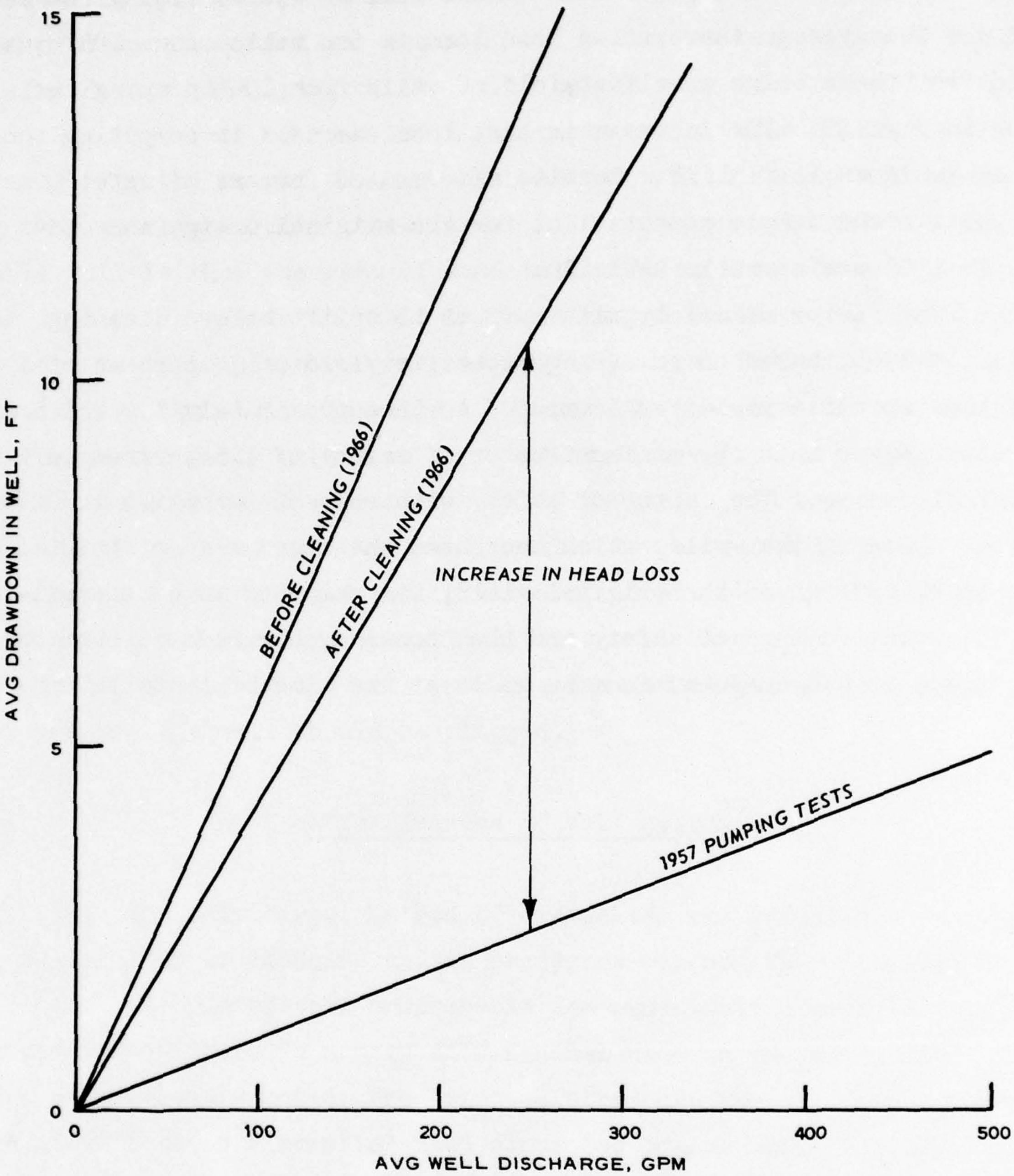
a. The well system, as installed, was capable of reducing the uplift pressure beneath the wells to those values computed for design.

b. The reduction in specific yields of the wells was due to an increase in head loss through the well filters and screens.

In the original design, the computed flow per well for a 20.5-ft

differential head was 228 gpm with an excess head of 4.1 ft midway between the wells. The average increase in head loss in the wells since 1957 was obtained from the average specific yield of wells from 1966 pumping tests as shown in fig. A7. The increase in head loss was used in computing the excess heads shown in fig. A8. Results of computed factors of safety against uplift and sample computations for the original design and conditions in 1966 are shown in table A6.

24. The factor of safety with respect to uplift before cleaning the wells in 1966, based on an average specific yield of 34 percent of the original specific yield, was computed to be approximately 1.9 which is somewhat larger than the minimum factor of safety of 1.5 desired in the original design. The factor of safety with respect to uplift in 1966 after cleaning the wells, which increased the average specific yield from 34 to 47 percent of the original yield, was computed to be approximately 2.2. The factors of safety are thus considerably reduced from the values of 3.3 to 4.8 computed for the wells at the time of installation.



NOTE: AVERAGE SPECIFIC YIELD OF WELLS FROM 1957 PUMPING TESTS = 52.3 GPM/FT DRAWDOWN.

AVG WELL EFFICIENCY FROM 1966 PUMPING TESTS:

a) 35% OF 1957 SPECIFIC YIELD BEFORE WELL CLEANING.

b) 47% OF 1957 SPECIFIC YIELD ATER WELL CLEANING.

Fig. A7. Head losses due to decrease in average well efficiency

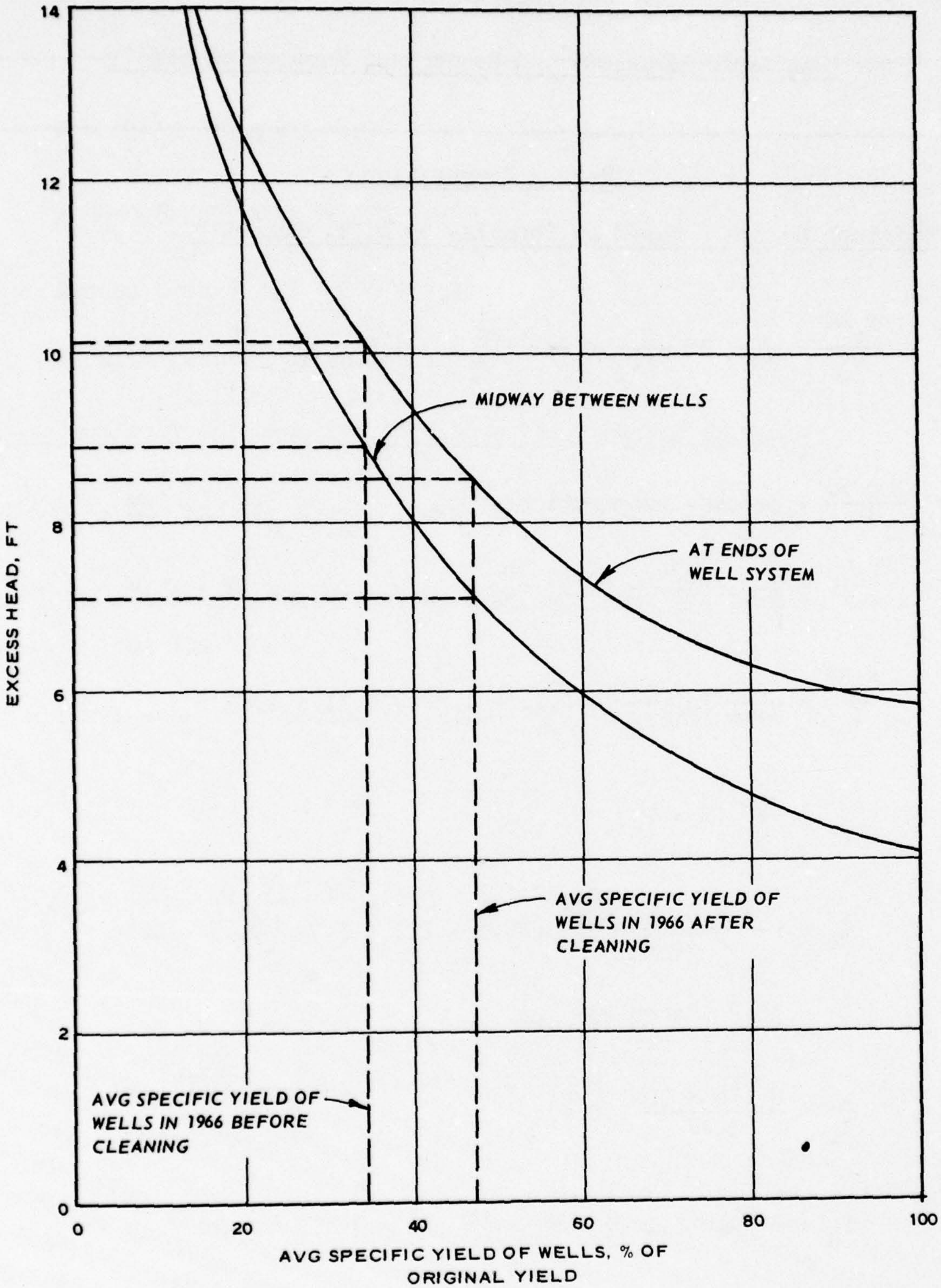


Fig. A8. Well efficiency versus excess head

Table A6

Sample Computations and Summary of Factors of Safety

Sample Computations

A. Original design - based on formulas by P. T. Bennett*

$$\frac{P_a kd}{Q_w} = \frac{d}{2\pi zw} \ln \frac{a}{2\pi r_w} + 0.11 \left(\frac{d}{a} - 1\right)\left(\frac{d}{zw} - 1\right)$$

where

$$\frac{100\ zw}{d} = \text{percent penetration} = 50\%$$

$$= \frac{2}{2\pi} \ln \frac{184}{2\pi} + 0.11 \left(\frac{90}{184} - 1\right)(2 - 1) = 1.52 - 0.06 = 1.46$$

$$\frac{P_m kd}{Q_w} = \frac{d}{2\pi zw} \ln \frac{a}{2\pi r_w} + 0.11 = 1.52 + 0.11 = 1.63$$

$$Q_w = \frac{akd}{S} (H - P_a)$$

$$Q_w = \frac{184 \times 0.158 \times 90}{1500} (20.5 - P_a) = 1.74 \left(20.5 - 1.46 \frac{Q_w}{kd}\right)$$

$$= 30.2 \text{ cfm or } 228 \text{ gpm}$$

$$\frac{kd}{Q_w} = \frac{0.158 \times 90}{30.2} = 0.47$$

$$P_a = \frac{1.46}{0.47} = 3.1 \text{ ft}$$

(Continued)

* "Relief Well Design," Civil Works Engineer Bulletin 55-11, 28 June 1955.

Table A6

Sample Computations and Summary of Factors of Safety

Sample Computations

A. Original design - based on formulas by P. T. Bennett*

$$\frac{P_a kd}{Q_w} = \frac{d}{2\pi zw} \ln \frac{a}{2\pi r_w} + 0.11 \left(\frac{d}{a} - 1\right)\left(\frac{d}{zw} - 1\right)$$

where

$$\frac{100\ zw}{d} = \text{percent penetration} = 50\%$$

$$= \frac{2}{2\pi} \ln \frac{184}{2\pi} + 0.11 \left(\frac{90}{184} - 1\right)(2 - 1) = 1.52 - 0.06 = 1.46$$

$$\frac{P_m kd}{Q_w} = \frac{d}{2\pi zw} \ln \frac{a}{2\pi r_w} + 0.11 = 1.52 + 0.11 = 1.63$$

$$Q_w = \frac{akd}{S} (H - P_a)$$

$$Q_w = \frac{184 \times 0.158 \times 90}{1500} (20.5 - P_a) = 1.74 \left(20.5 - 1.46 \frac{Q_w}{kd}\right)$$

$$= 30.2 \text{ cfm or } 228 \text{ gpm}$$

$$\frac{kd}{Q_w} = \frac{0.158 \times 90}{30.2} = 0.47$$

$$P_a = \frac{1.46}{0.47} = 3.1 \text{ ft}$$

(Continued)

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* "Relief Well Design," Civil Works Engineer Bulletin 55-11, 28 June 1955.

$$P_m = \frac{1.63}{0.47} = 3.5 \text{ ft}$$

$$H_w \simeq 0.6 \text{ ft for } Q_w = 228 \text{ gpm}$$

Excess head = 3.5 + 0.6 = 4.1 ft

$$\text{FS with respect to uplift} = \frac{1230}{4.1 \times 62.5} = 4.8$$

B. Based on well efficiencies in 1966 after cleaning of wells

$$Q_w = \frac{akd}{S}(H - h_w - P_a)$$

where h_w = increase in head loss between 1957 and 1966 pumping tests determined from fig. A7.

Using a trail-and-error procedure assume Q_w = 178 gpm, then h_w = 3.8 ft

$$H_w = 3.8 + 0.6 = 4.4 \text{ ft}$$

$$Q_w = \frac{184 \times 0.158 \times 90}{1500}(20.5 - 4.4 - P_a)$$

where

$$P_a = 1.46 \frac{Q_w}{kd}$$

$$Q_w = 28.0 - 0.179\, Q_w$$

$$= 23.7 \text{ cfm or } 178 \text{ gpm (in agreement with assumed value)}$$

$$\frac{kd}{Q_w} = \frac{0.158 \times 90}{23.7} = 0.601$$

$$P_m = \frac{1.63}{0.601} = 2.71$$

(Continued)

Table A6 (Concluded)

Excess head = 2.7 + 4.4 = 7.1 ft

$$\text{FS with respect to uplift} = \frac{1230}{7.1 \times 62.5} \doteq 2.8$$

Summary of Factors of Safety

	Original Design		1966 Before Cleaning		1966 After Cleaning	
	Midway	Ends	Midway	Ends	Midway	Ends
Excess head, ft	4.1	5.9	8.9	10.1	7.1	8.5
Factor of safety (FS)	4.8	3.3	2.2	1.9	2.8	2.3

PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

25. On the basis of the tests and analysis presented herein, the following conclusions appear warranted:

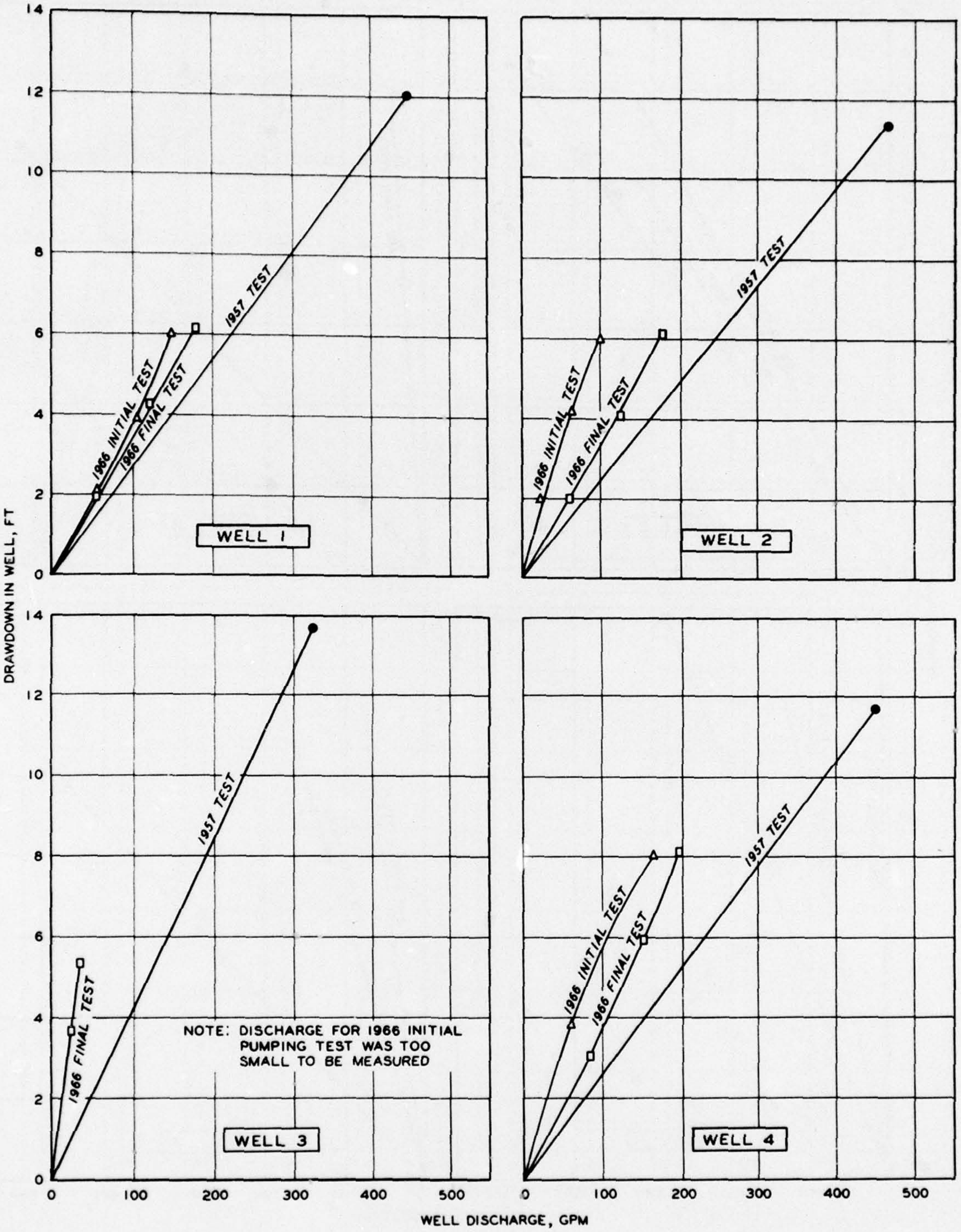
- a. The efficiency of the relief well system before cleaning in 1966 showed a significant reduction in average specific yield from as-installed values and a corresponding reduction in factors of safety with respect to uplift. The well system was designed to accommodate a substantial reduction in well efficiency with time. The factor of safety with respect to uplift of 1.9 before cleaning the wells is somewhat larger than the minimum factor of safety of 1.5 considered desirable.
- b. Cleaning of the wells in 1966 increased the specific yield of the wells from an average of 34 percent of the original yield to 47 percent of the original yield. This increased the factor of safety with respect to uplift to 2.3.
- c. Analysis of water samples indicated that conditions are such that incrustations or tuberculations may form. The water was somewhat corrosive, although not excessively so; however, this fact should have little bearing on the decrease in efficiency of the wells with time.

Recommendations

26. It is recommended that:

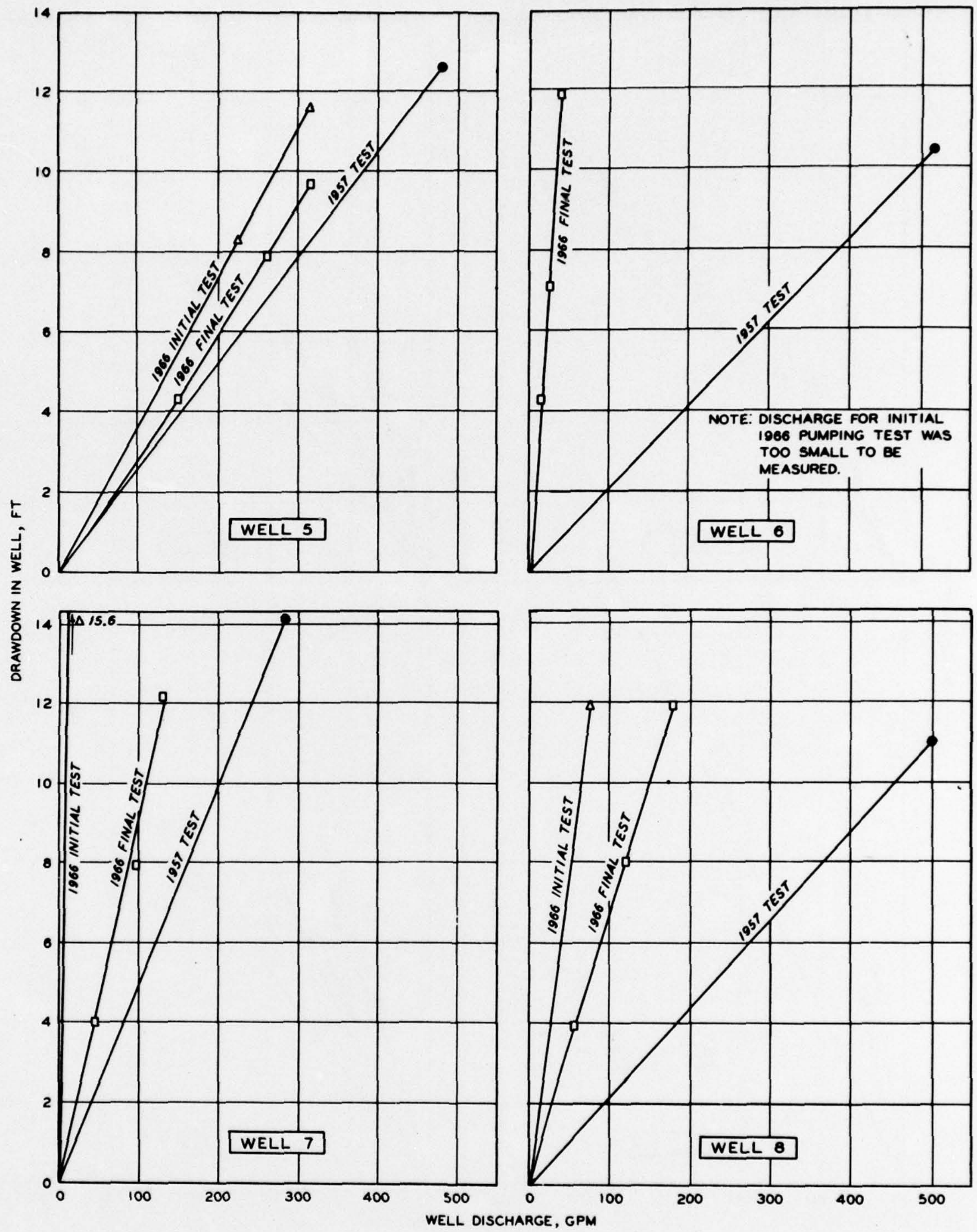
- a. Well pumping tests and cleaning operations be continued for all wells at 2-yr intervals. If the efficiency of these wells continues to decrease with time, remedial measures should be considered. Such measures may require new wells downstream of the stilling basin in order to maintain a factor of safety of at least 1.5.
- b. During the next well pumping tests and cleaning operations, well 2 be checked for sand infiltration. If the well produces sand at a rate greater than 2 pt/hr after 8 hr continuous pumping, the well should be plugged.
- c. A few of the wells be test-treated with chemicals that may be potentially suitable for cleaning the wells.
- d. Upper gaskets of the well outlets be replaced with new gaskets of better quality within the next year or so.

e. Some of the wells be inspected with a borehole TV camera to determine the extent and probable cause of misalignment of the riser pipes, and to obtain information on the degree and characteristics of clogging of the well screen slots.



WELL DISCHARGE VS MEASURED DRAWDOWN

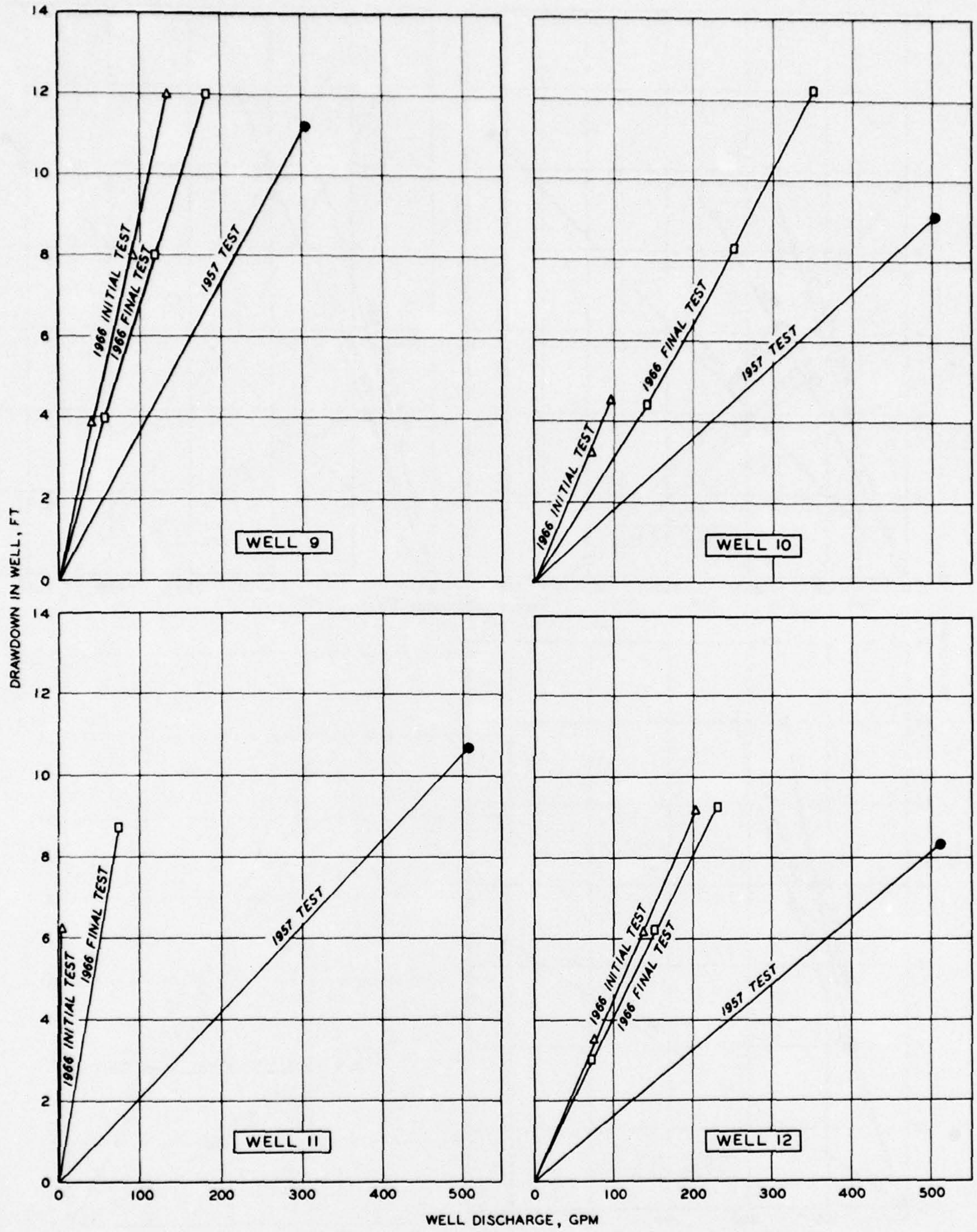
WELLS 1-4



WELL DISCHARGE VS MEASURED DRAWDOWN

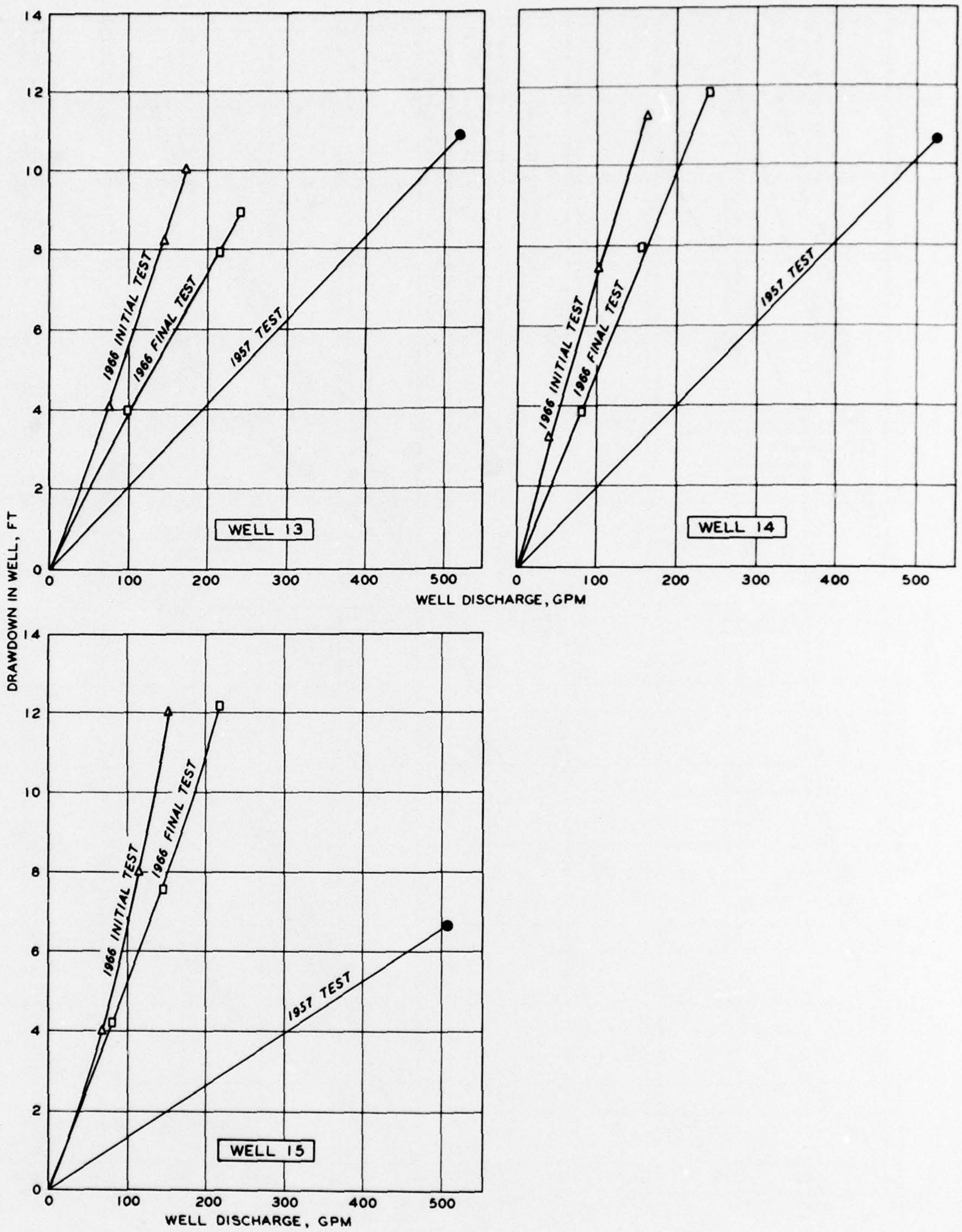
WELLS 5-8

PLATE A2



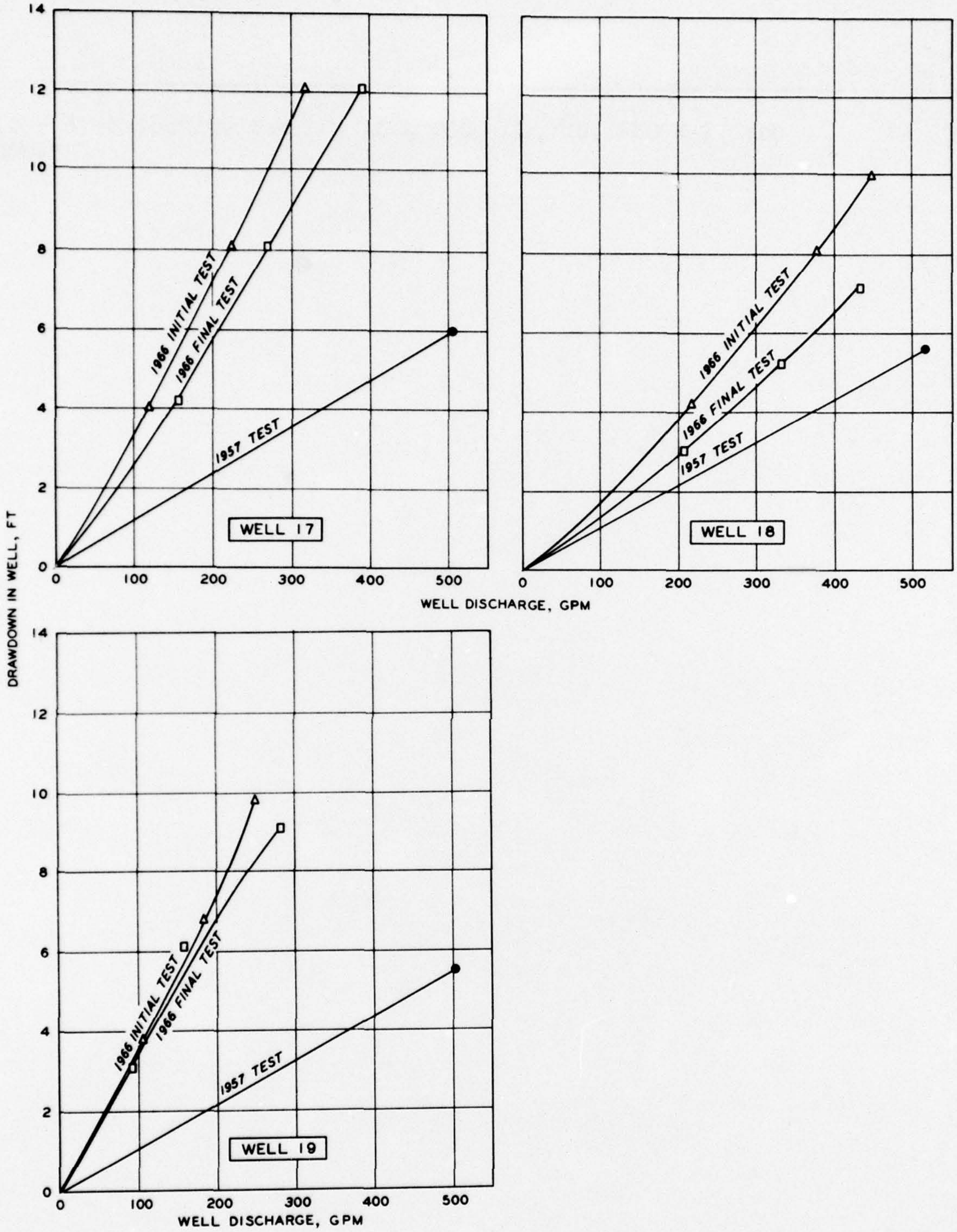
WELL DISCHARGE VS MEASURED DRAWDOWN

WELLS 9–12



WELL DISCHARGE VS
MEASURED DRAWDOWN

WELLS 13–15



WELL DISCHARGE VS
MEASURED DRAWDOWN

WELLS 17-19

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13. ABSTRACT This is the first in a series of reports presenting the results of tests performed at intervals of several years on the relief wells at the overbank structure near Natchez, Miss. The tests, performed in 1966, included well pumping tests, analysis of well water samples, and well sounding and cleaning. These tests were conducted to determine the extent to which the efficiency of the relief wells had decreased since their installation in 1957 and to clean by surging those wells with specific yields of 80% and less of their original yields. Chemical analyses of well water samples indicate that the water is somewhat corrosive and contains a large amount of iron. In the presence of bacteria, incrustation or tuberculation of the well screens may occur under these conditions. Prior to pumping tests, each well was sounded to determine the thickness of sediment in the well. Thicknesses varied from 0.0 to 8.9 ft; most of the sediment entered the wells after 1957. The measured thickness of sediment after pumping and cleaning varied from 0.0 to 2.1 ft. Initial pumping tests indicated specific yields from 0 to 71% of the original yield, with an average of about 34%. After the wells were surged, the specific yields increased to 6 and 87% of the original yields and averaged about 47%. The rate of sand infiltration was determined by measuring the amount of sand entering the wells during pumping tests. Infiltration rates varied from none to 21 pints per hour in one well. Several wells may not be stable, as indicated by the high rate of sand infiltration. The effectiveness of the well system in reducing uplift pressures was evaluated from factors of safety (FS) against uplift, computed by considering the increased head loss through well filters and screens observed in pumping tests. The computed FS was about 1.9 before cleaning and 2.2 after cleaning. In the original design, the computed FS was 3.3.

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Relief wells						
Soil infiltration						
Well pumping tests						

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